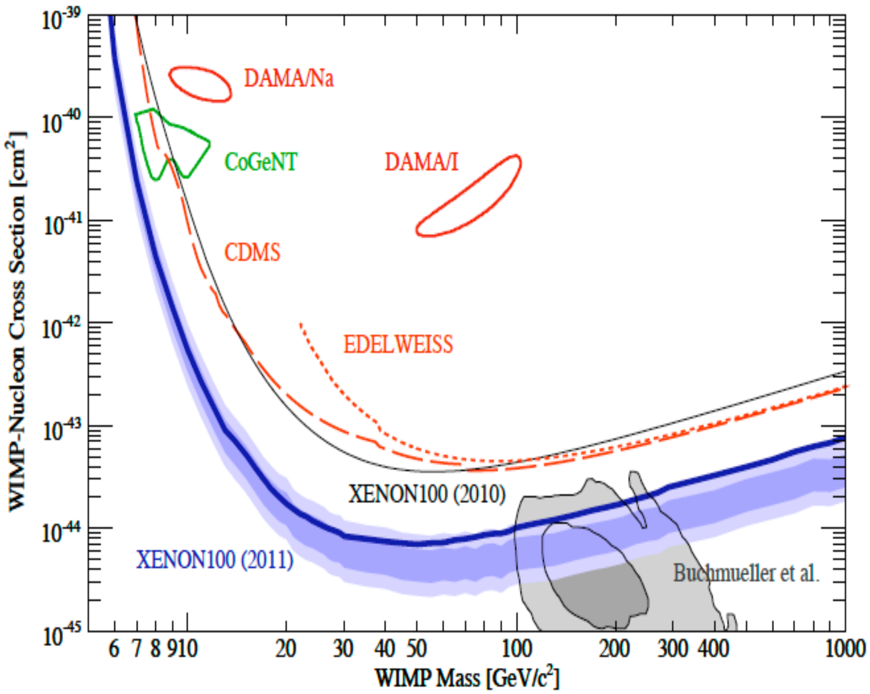
Fine-Tuning Implications of Direct Dark Matter Searches in the MSSM

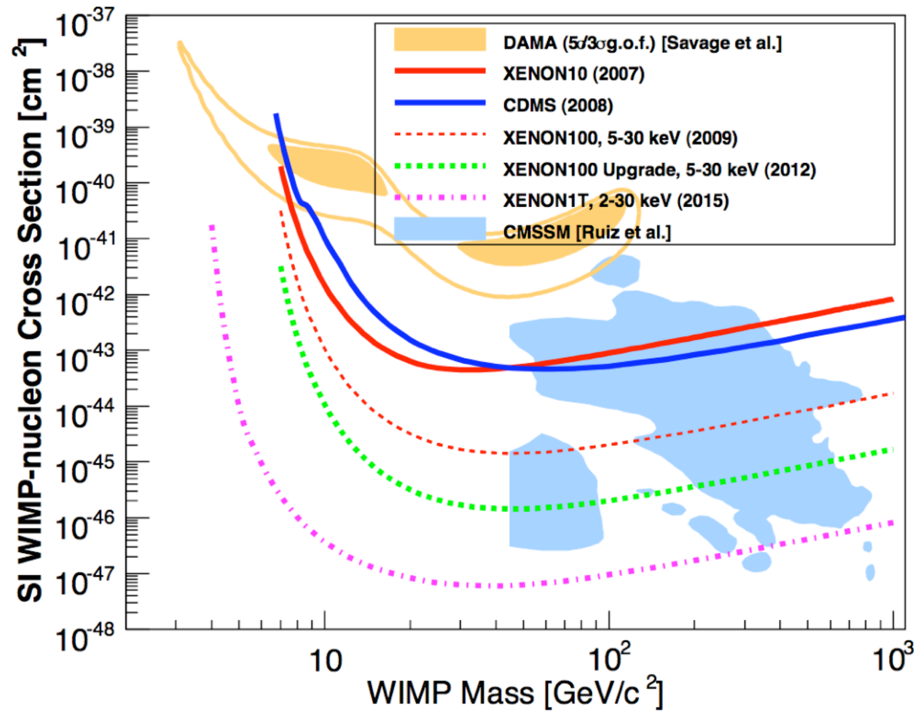
Bibhushan Shakya
Cornell University

SUSY 2011
August 30, 2011

Based on arXiv:1107.5048 with Maxim Perelstein

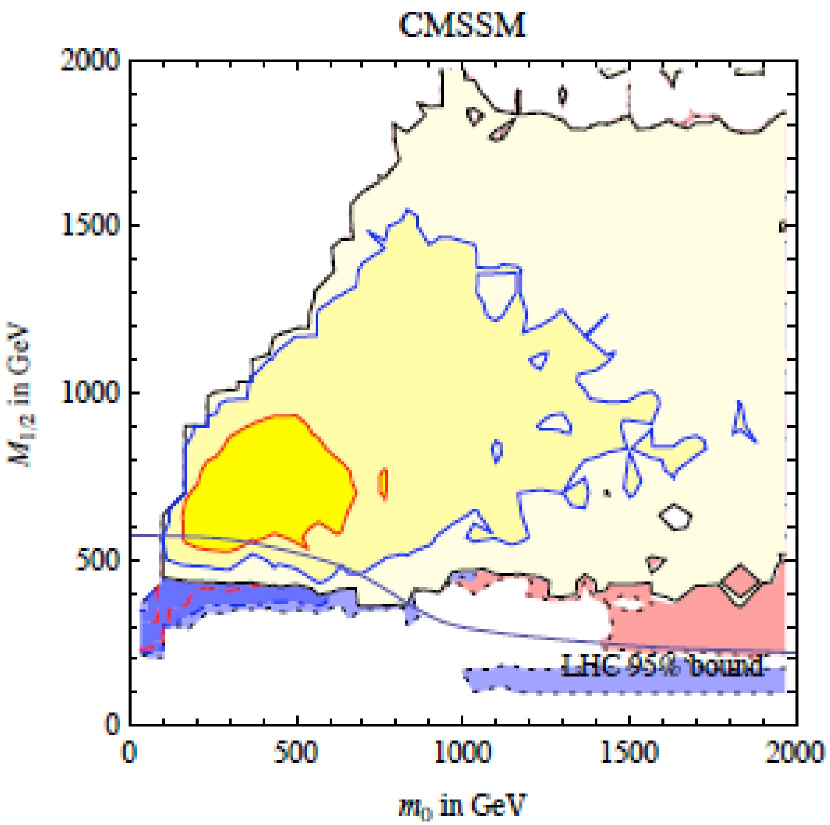
Direct detection experiments are beginning to probe interesting regions of MSSM parameter space

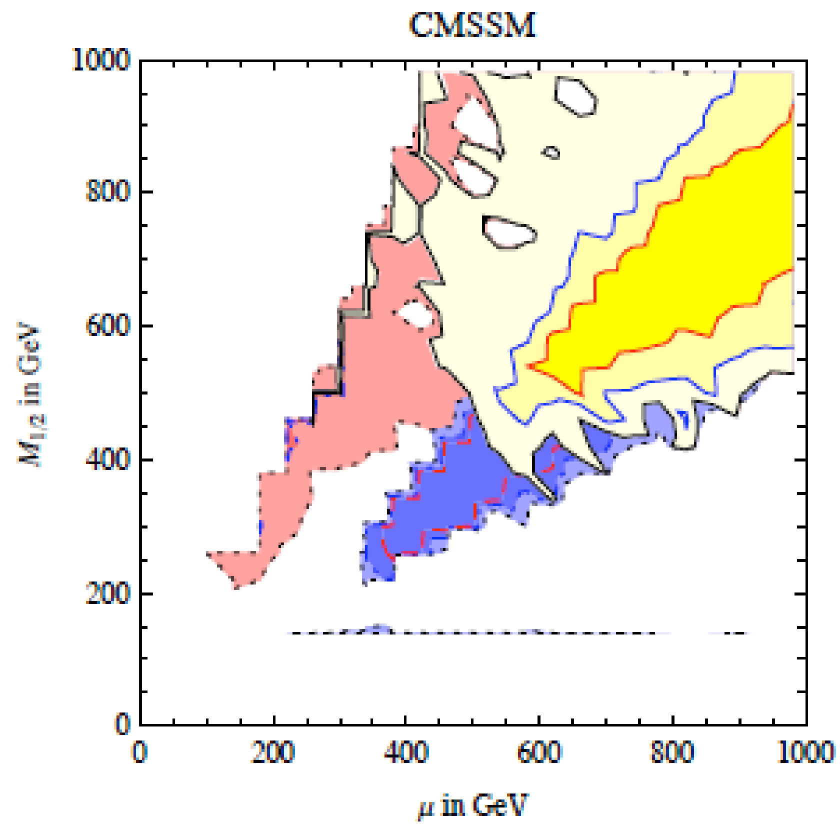




Future upgrades will probe lower cross sections

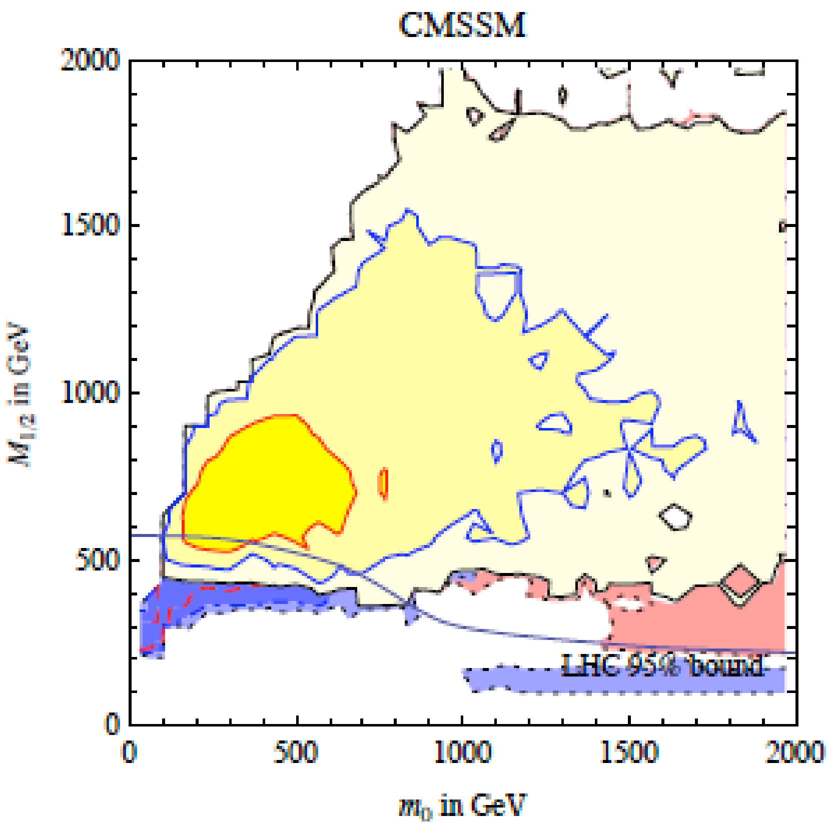
Null results $\Rightarrow$ Bounds on parameter combinations

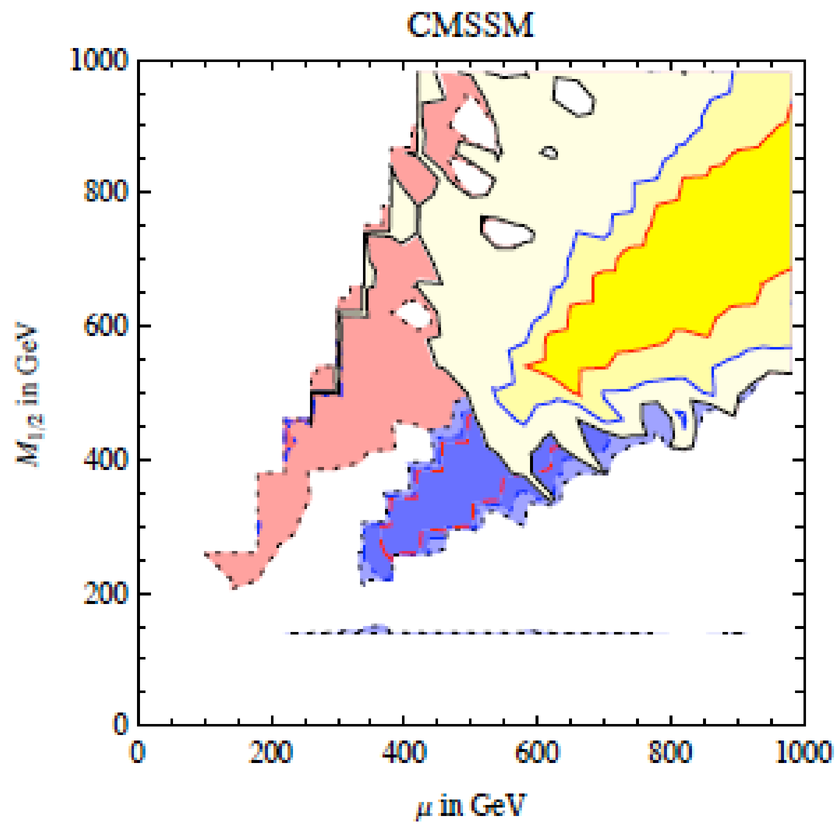




hep-ph 1104.3572

Null results ⇨ Bounds on parameter combinations





hep-ph 1104.3572

What does it mean for generic SUSY models??

A meaningful measure:

Fine-tuning

A meaningful measure:

Fine-tuning

- In EW sector, MSSM parameters must reproduce the correct m_Z

$$m_Z^2 = -m_u^2\left(1 - \frac{1}{\cos 2\beta}\right) - m_d^2\left(1 + \frac{1}{\cos 2\beta}\right) - 2|\mu|^2$$

- Calculate sensitivity to small changes in MSSM parameters:

$$\delta(\xi) = \left|\frac{\partial \log m_Z^2}{\partial \log \xi}\right| \qquad \xi = m_u^2, m_d^2, b, \mu$$

- Add these in quadrature → a measure of EWSB fine-tuning
- Fine tuned for large μ and (to lesser extents) large m_A and small tan β

A meaningful measure:

Fine-tuning

The Question:

In generic MSSM, is there a correlation between direct detection cross section and fine tuning?

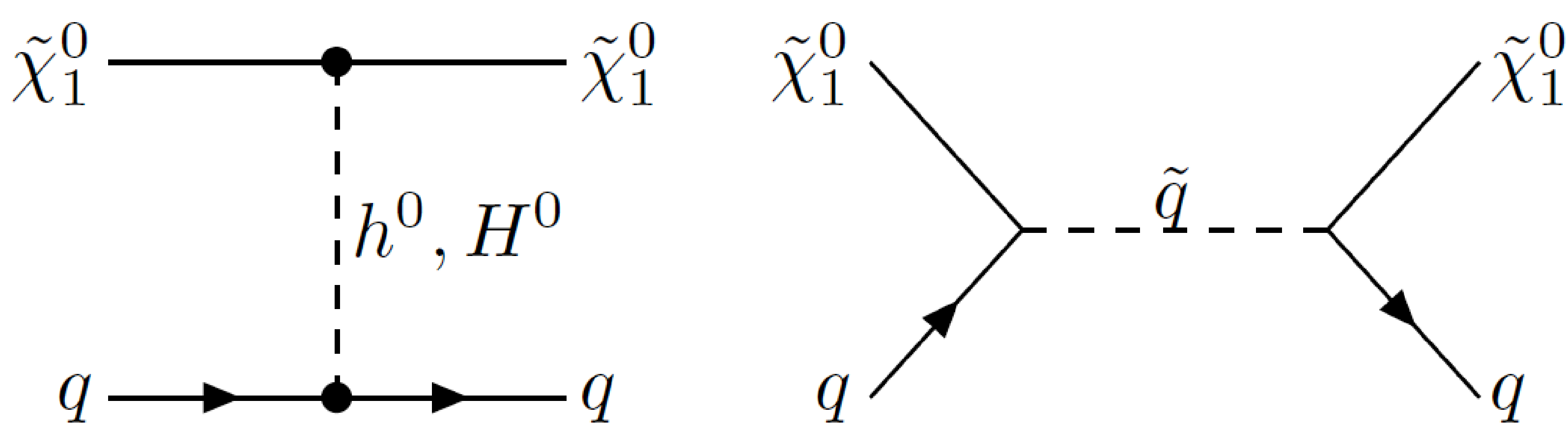
(ie, are lower cross sections more fine-tuned?)

Philosophy:

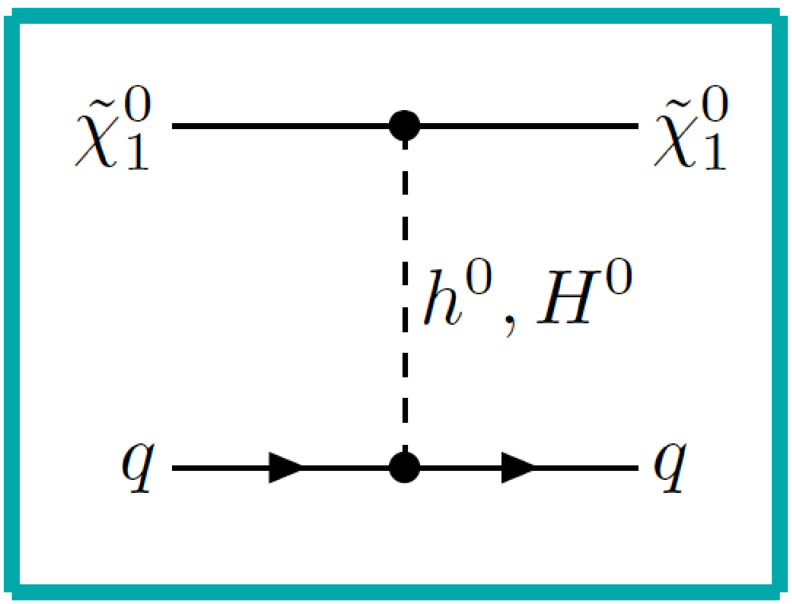
Assume no relations between weak-scale MSSM parameters

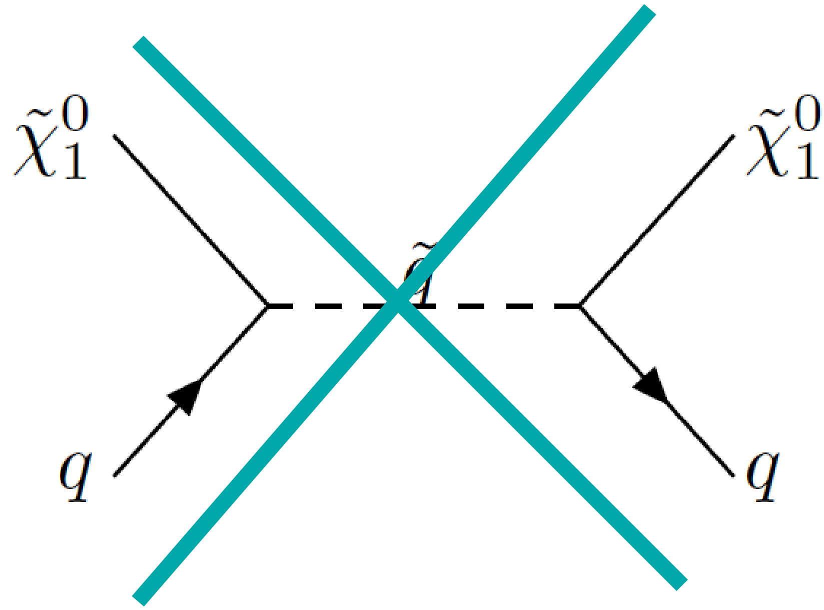
No accidental cancellations (want to make general statements valid in most of the parameter space)

Spin independent scattering



Spin independent scattering





Ignore this contribution

Direct detection cross section depends only on

$$p_i = (M_1, M_2, \mu, \tan\beta, m_A)$$

These same parameters enter fine-tuning!

Approach

- Scan over parameters $p_i = (M_1, M_2, \mu, \tan\beta, m_A)$
- Fix Higgs mass at m_H=120 GeV

$$|M_1| \in [10, 10^4]\ \mathrm{GeV}; \qquad |M_2| \in [80, 10^4]\ \mathrm{GeV};$$
$$\mu \in [80, 10^4]\ \mathrm{GeV}; \qquad m_A \in [100, 10^4]\ \mathrm{GeV};$$
$$\tan\beta \in [2, 50]\,.$$

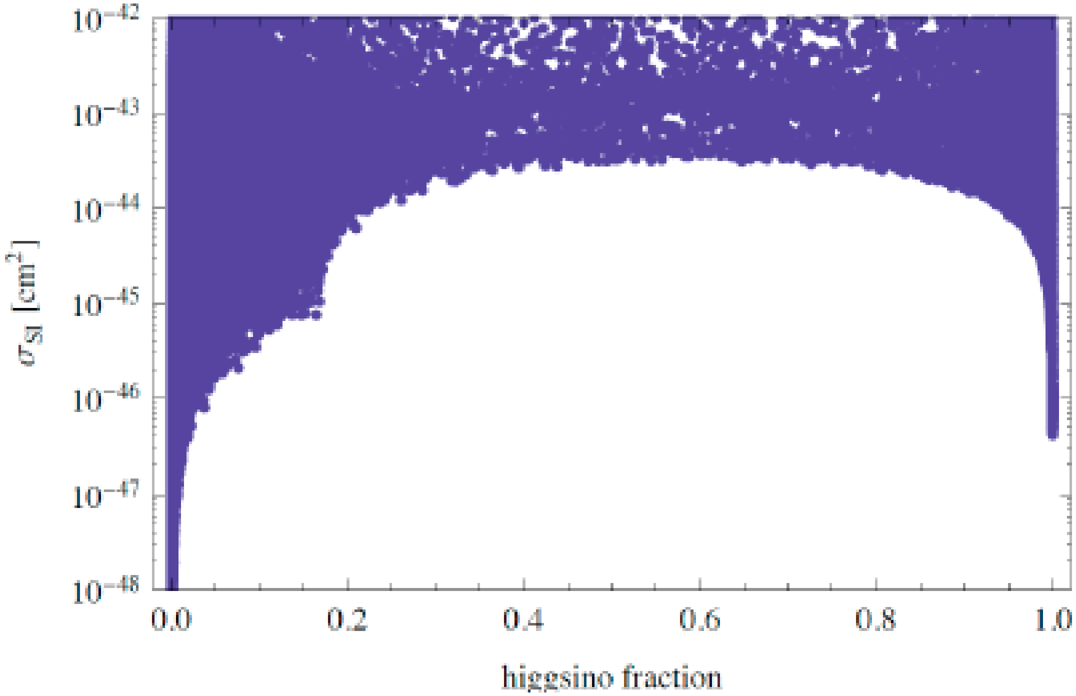
- Requirements:

  neutralino LSP, charginos heavier than 100 GeV

- Scan with all real, positive parameters (next few slides), then look at cases where parameters are negative or complex

LSP Neutralino content

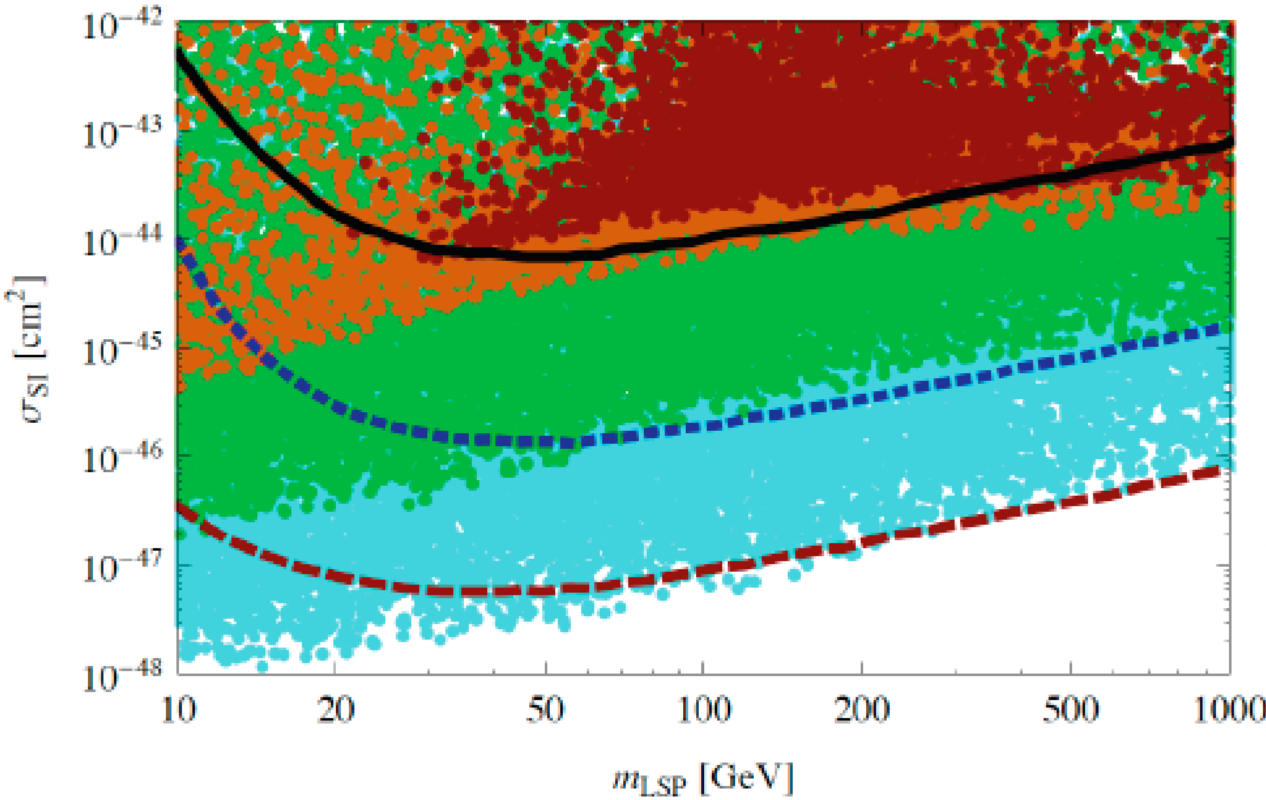
$$\tilde{\chi}_1^0 = Z_{\chi 1}\tilde{B} + Z_{\chi 2}\tilde{W}^3 + Z_{\chi 3}\tilde{H}_d^0 + Z_{\chi 4}\tilde{H}_u^0$$



$$\tilde{\chi}^0\tilde{\chi}^0 h: \qquad (gZ_{\chi 2} - g'Z_{\chi 1})(\cos\alpha Z_{\chi 4} + \sin\alpha Z_{\chi 3})$$

$$\tilde{\chi}^0\tilde{\chi}^0 H: \qquad (gZ_{\chi 2} - g'Z_{\chi 1})(\sin\alpha Z_{\chi 4} - \cos\alpha Z_{\chi 3})$$

LSP Neutralino content



Content "purity"
Red: >0.2
Orange; 0.1-0.2
Green: 0.01-0.1
Cyan: 0.001-0.01

Black, blue, red curves:
Xenon100,
Xenon100 w/ upgrade,
Xenon1T

Xenon100 results are forcing us into pure gaugino or pure higgsino regions

Gaugino Dark Matter and Fine-Tuning

$M_1 < \mu$ or $M_2 < \mu$

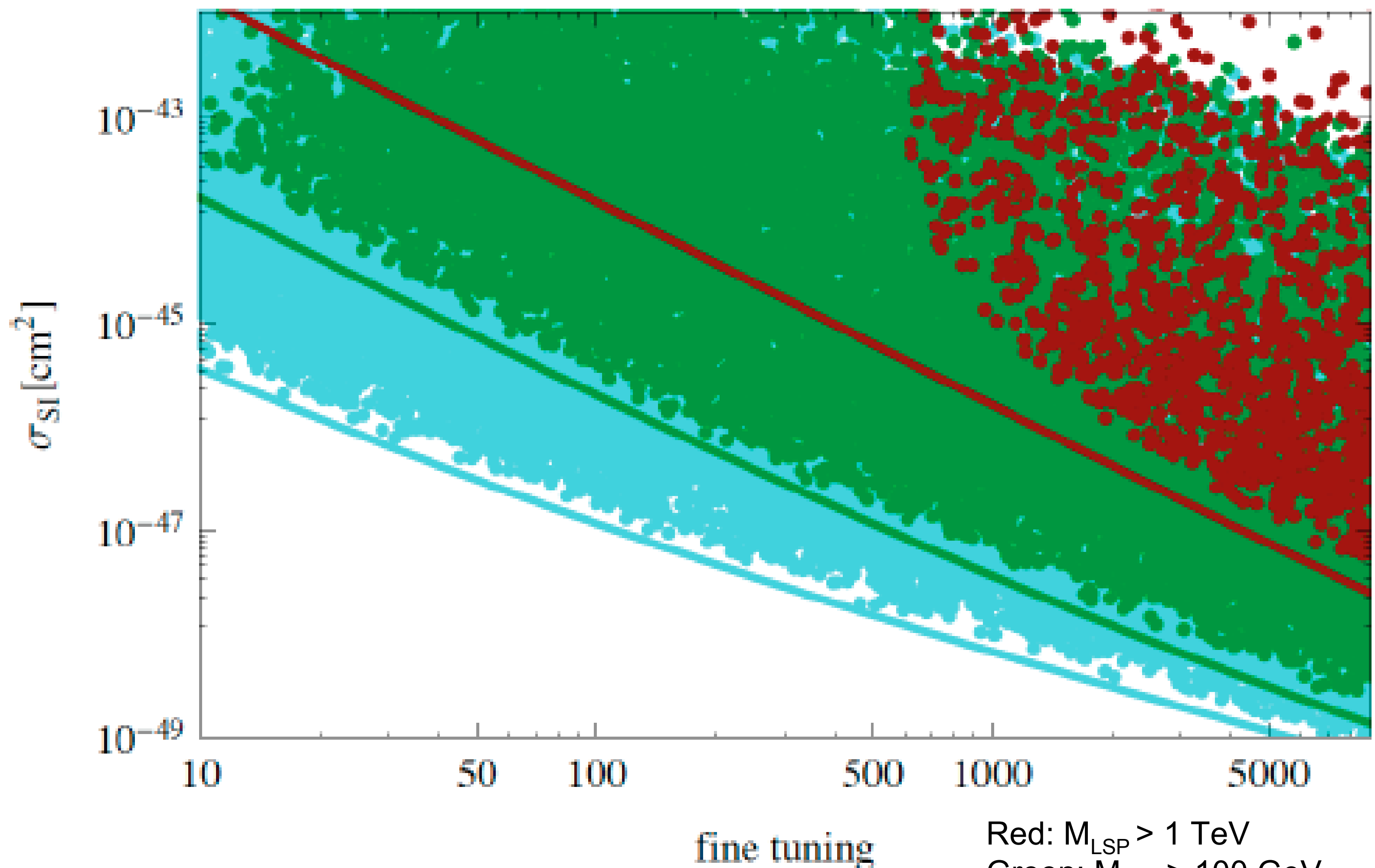
Can derive an approximate, analytic bound
(for all real, positive parameters):

$$\sigma_{\min} = (1.2 \times 10^{-42}\ \mathrm{cm}^2) \left(\frac{120\ \mathrm{GeV}}{m_h}\right)^4 \frac{1}{\Delta} \left(\frac{1}{\tan\beta} + \frac{1}{\sqrt{\Delta}} \frac{M_{\mathrm{LSP}}}{m_Z}\right)^2$$

Also see hep-ph/0606134

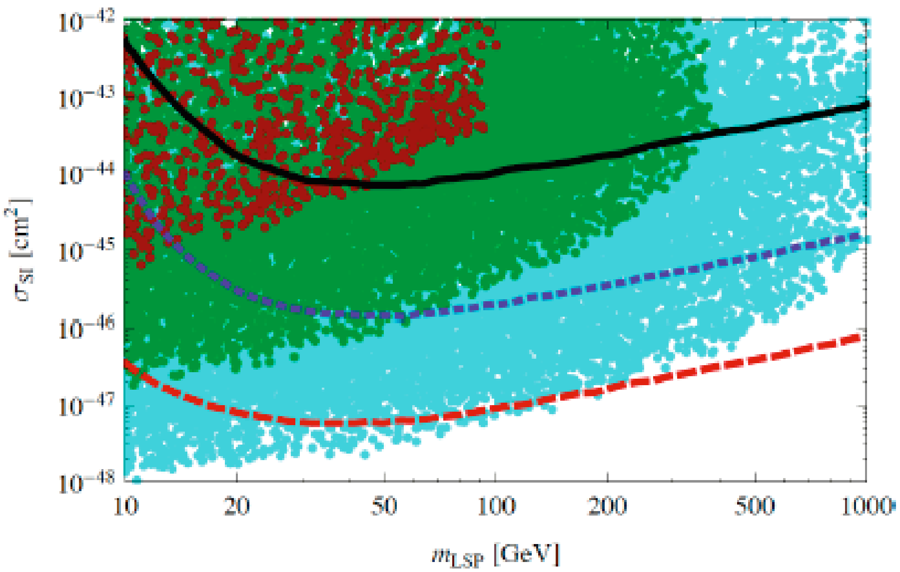
$\Rightarrow$ For a given LSP mass, a lower cross section requires greater fine-tuning!

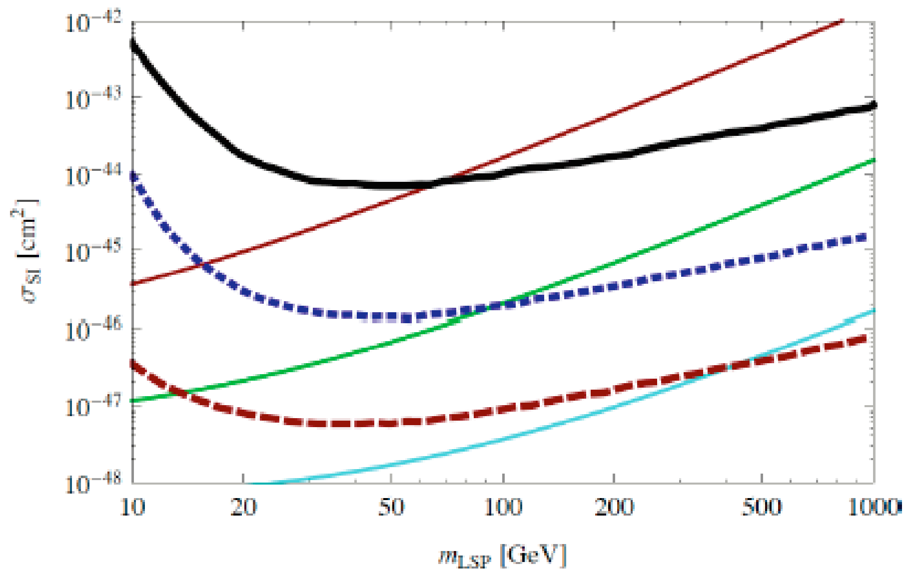
Gaugino Dark Matter and Fine-Tuning



Red: $M_{LSP} > 1$ TeV
Green: $M_{LSP} > 100$ GeV
Cyan: $M_{LSP} > 10$ GeV

Gaugino Dark Matter and Fine-Tuning





Fine-tuning: Red, green, cyan: >10,100,1000

- Current Xenon bound → More than 10% fine-tuning above 70 GeV
- Xenon 1T will probe regions with fine-tuning down to percent level

Higgsino Dark Matter

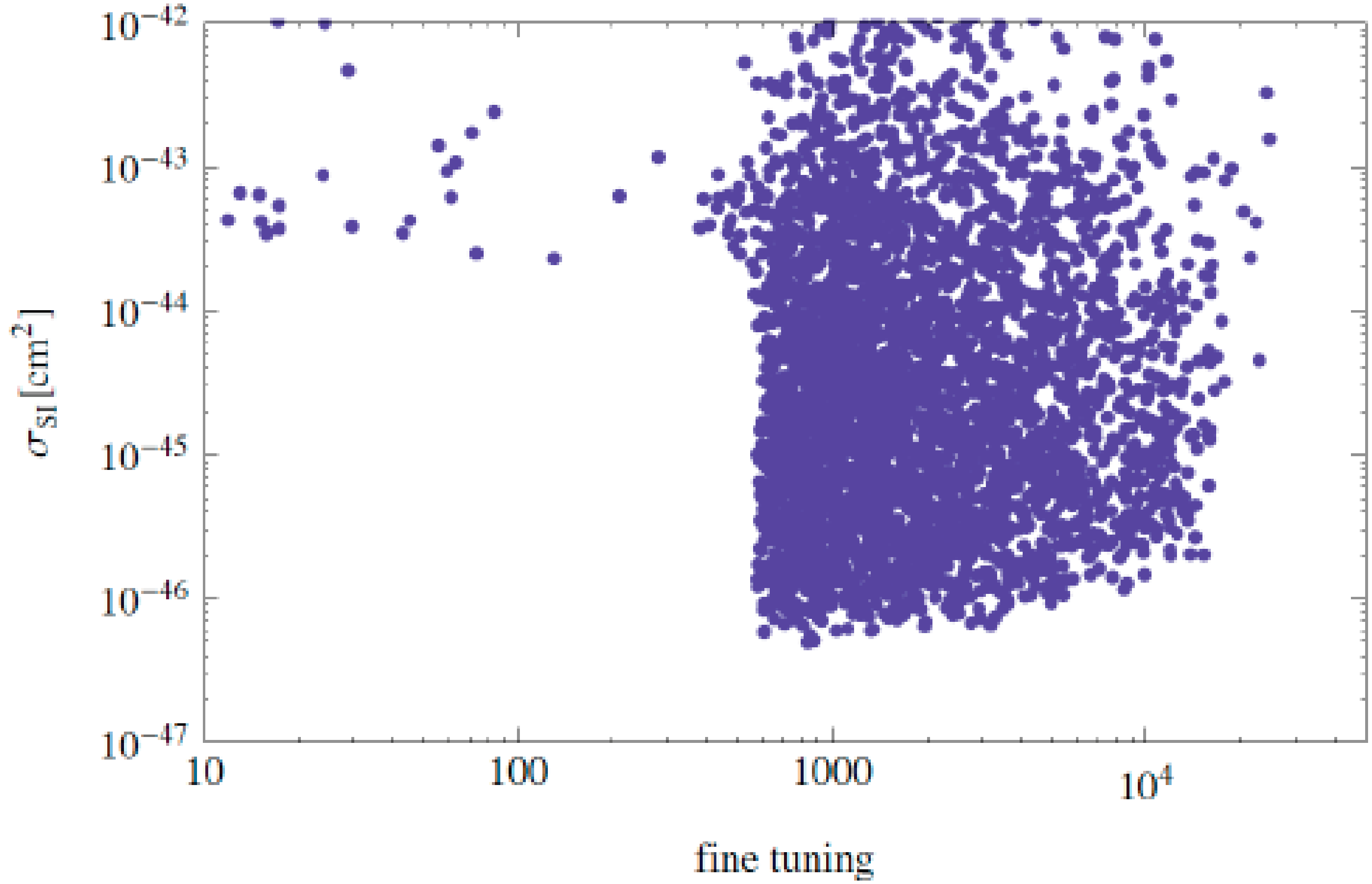
$\mu < M_1, M_2$

coupling
$$\tilde{\chi}^0\tilde{\chi}^0 h: \qquad (gZ_{\chi 2} - g'Z_{\chi 1})(\cos\alpha Z_{\chi 4} + \sin\alpha Z_{\chi 3})$$
$$\tilde{\chi}^0\tilde{\chi}^0 H: \qquad (gZ_{\chi 2} - g'Z_{\chi 1})(\sin\alpha Z_{\chi 4} - \cos\alpha Z_{\chi 3})$$

Can keep μ small and avoid fine-tuning, but increase M_1, M_2 and suppress direct detection cross section

Need additional constraint:
require relic density to equal/exceed observed relic density
(we are ignoring contributions from squarks, including them will lead to larger annihilation cross sections and lower relic density)

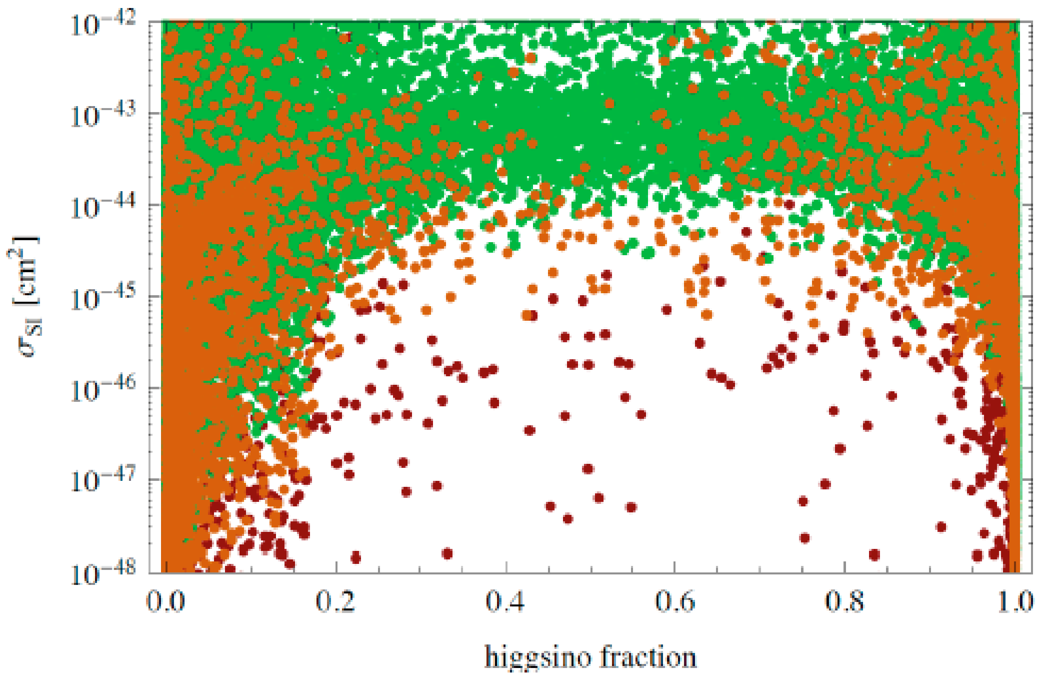
Higgsino Dark Matter



Negative Parameters

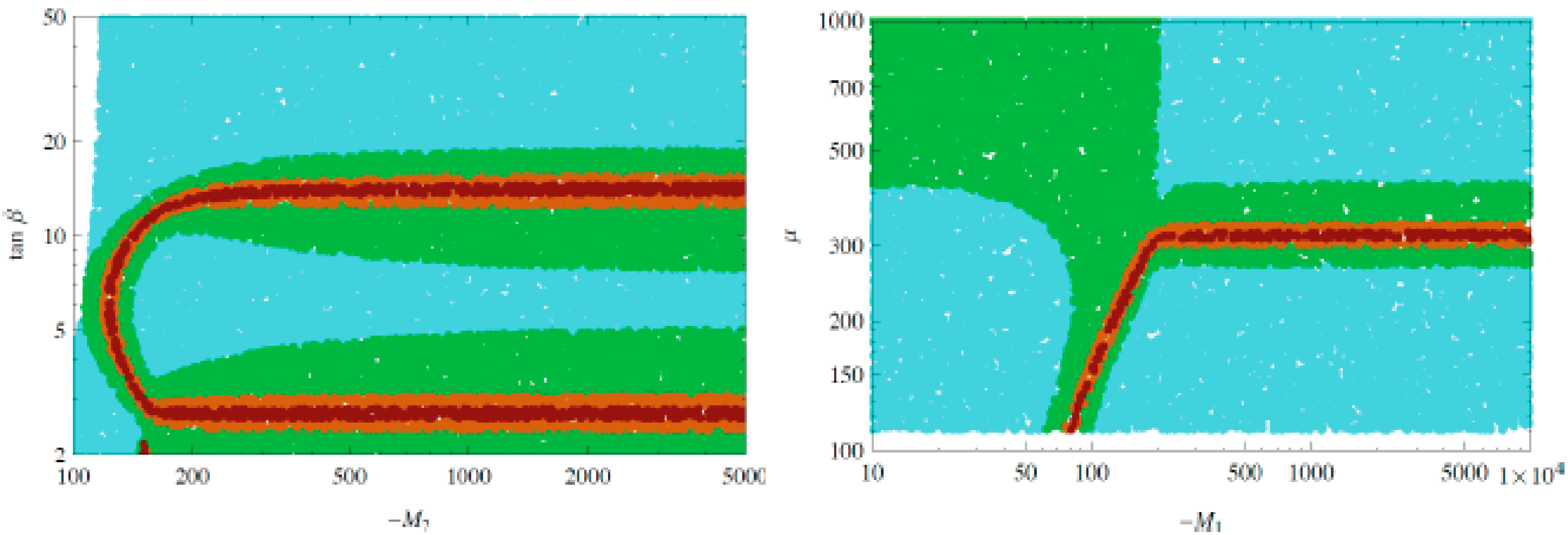
(Choose basis where M_1, M_2 can be negative)

- Accidental cancellations between contributions possible, aforementioned correlations no longer hold



Negative Parameters

However, such cases themselves require parameters to be tuned to achieve the right cancellation

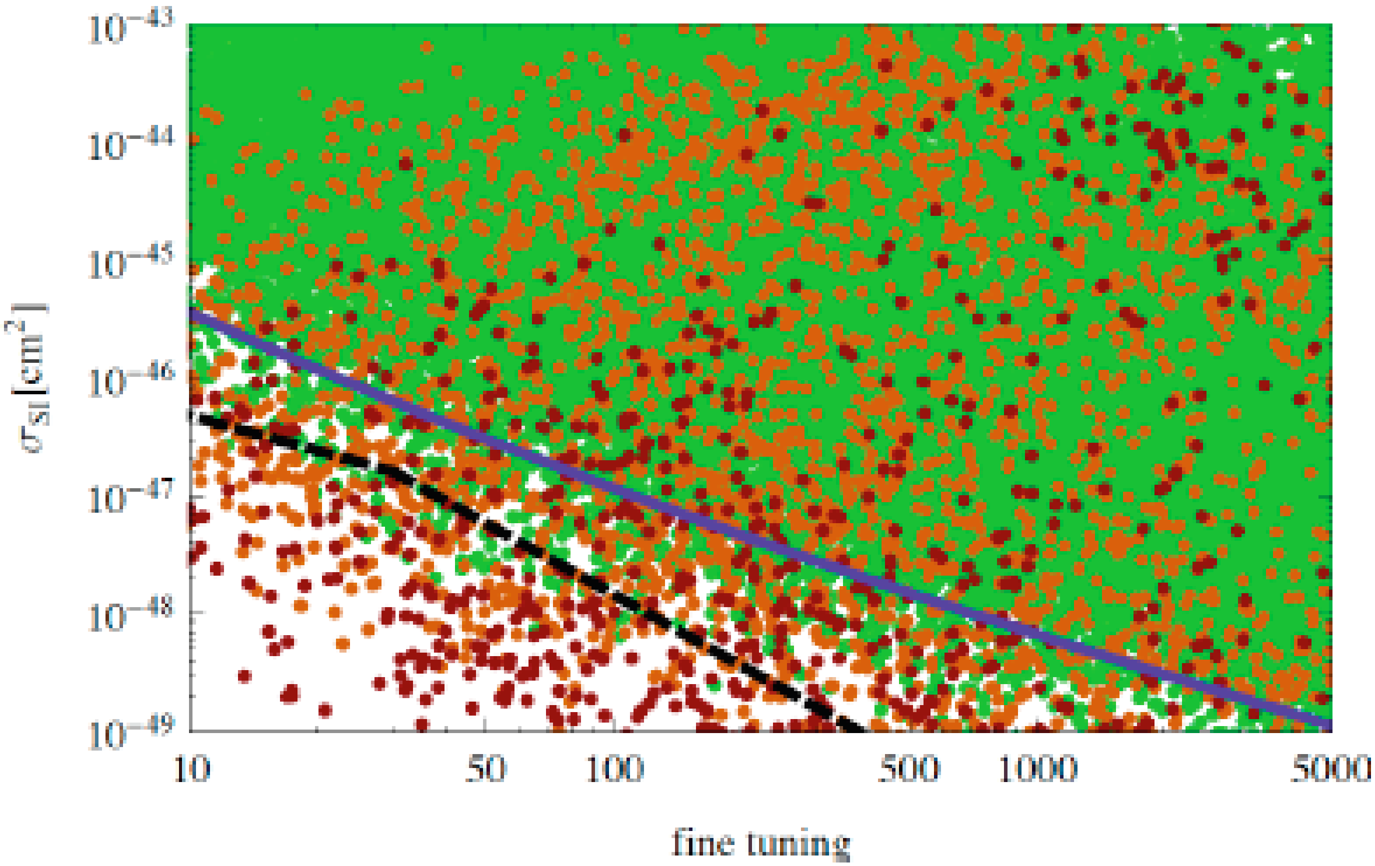


Red, orange, green, cyan: $\log_{10}\sigma$ < -47,-46,-45, and above

Quantify this accidental cancellation in the same way as fine-tuning in the EWSB sector:

$$\Delta_{\rm acc} \equiv \sqrt{\sum_{i=1}^{5}\left(\frac{\partial \log\sigma}{\partial \log p_i}\right)^2}$$

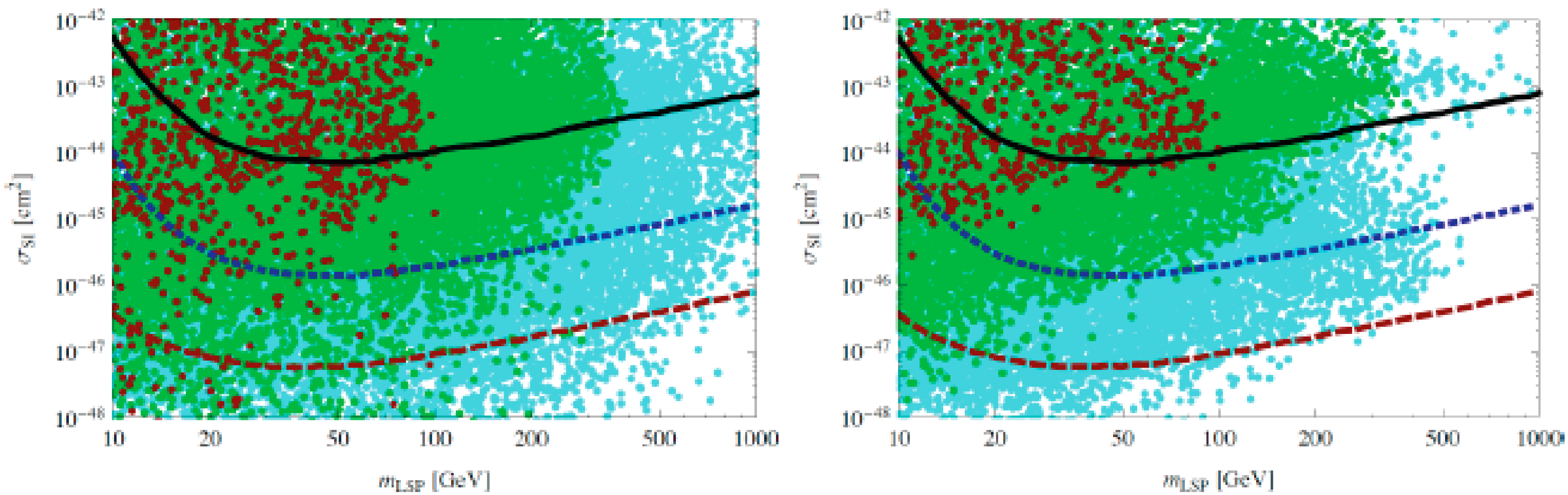
Negative Parameters



Red, orange, green: Δacc > 30,10, <10

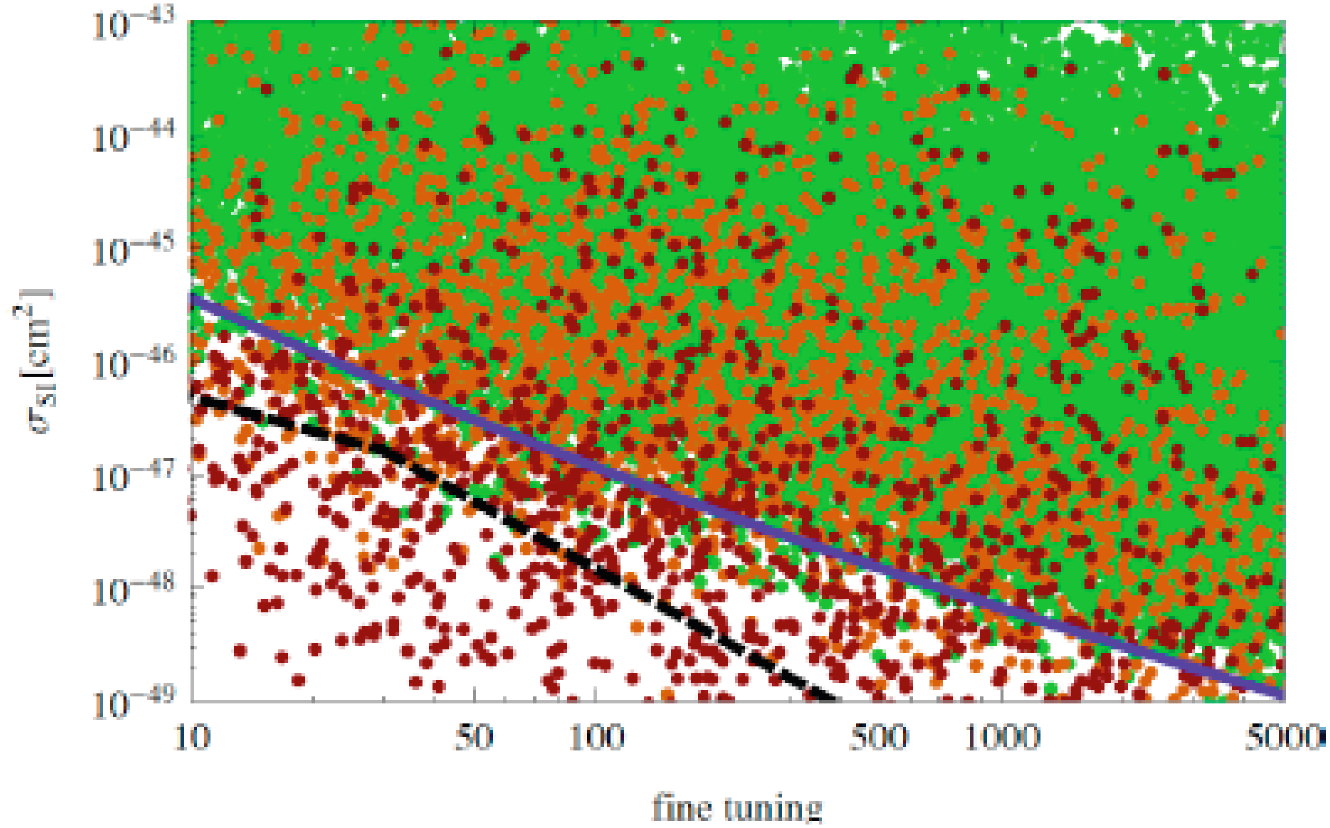
Negative Parameters

With and without points with accidental cancellations in direct detection cross section



Complex Parameters

(basis with M_1, M_2 complex)



Conclusions

- Current bounds require pure gaugino / higgsino LSP
- Gaugino LSP: smaller direct detection cross sections correlate with stronger fine-tuning; current Xenon100 bounds already imply ~10% tuning
- Higgsino LSP: Relic density constraint already seems to require sub-percent level fine-tuning
- Xenon1T can probe regions with fine tuning down to percent level
- Similar correlations may persist in the NMSSM (work in progress)